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A MODIFIED SURFACE FOR AN IMPLANTABLE DEVICE AND A METHOD OF PRODUCING THE SAME

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BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates generally to implantable devices, such as stents. More particularly, the invention relates to an implantable device having a modified surface and a method of modifying the surface.

Description of the Background

[0002] Blood vessel occlusions are commonly treated by mechanically enhancing blood flow in the affected vessel, such as by employing a stent. Stents act as scaffoldings, functioning to physically hold open and, if desired, to expand the wall of the passageway. Typically stents are capable of being compressed, so that they can be inserted through small lumens via catheters, and then expanded to a larger diameter once they are at the desired location.

[0003] Stents can be coated with various materials so as to provide therapeutic benefits in the treatment of an occluded vessel. For example, a stent can be coated with materials that provide the stent with increased biocompatibility, with lubrication for ease of positioning, with radiopacity or radioactivity for visualization, and with drug delivery capabilities.

[0004] It has been reported that coronary artery stents coated with titanium nitride oxide reduce neointimal hyperplasia in the porcine restenosis model. (Stephan Windecker et al., "Stent Coating with Titanium-Nitride-Oxide for Reduction of Neointimal Hyperplasia," Swiss Cardiovascular Center, University Hospital, Bern, Switzerland.) Neointimal hyperplasia generally refers to vascular smooth muscle cell migration and proliferation in response to an injury caused by intravascular interventions such as stenting. It is believed that neointimal hyperplasia contributes, at least in part, to restenosis, which is the re-narrowing of the vessel within weeks or months following intravascular treatment. Blood vessels in which significant restenosis occurs typically require further treatment. Accordingly, it is desirable to minimize neointimal hyperplasia and restenosis.

SUMMARY

[0005] In accordance with one aspect of the embodiments of the present invention, a medical device, such as a stent, is provided having a TiN_xO_y compound implanted at a depth within at least a region of a surface of the stent. The depth of the implanted TiN_xO_y compound can be less that 2000 angstroms from the surface of the stent. In one embodiment, a layer of TiN_xO_y compound can be deposited on the region of the surface of the stent where the TiN_xO_y compound is implanted. The stent can be made out of any suitable metallic material or alloy. The stent can, for example, be made from stainless steel. The surface of the stent being modified can be the outer or the tissue-contacting surface of the stent. In accordance with yet another embodiment, a layer of Ti, N, or TiN can be deposited beneath the layer of TiN_xO_y.

[0006] In accordance with another aspect of the invention, a device, such as a stent, is provided having a surface and a TiN_xC_y compound deposited on at lease a region of the surface of the device. In accordance with another aspect of the invention, a device, such as a stent, is provided having a surface and a TiN_xC_y compound implanted at a depth within at least a region of the surface of the stent.

[0007] In accordance with yet another aspect of the invention, a method of modifying a surface of a device, such as a stent, is provided, which method comprises implanting a TiN_xO_y compound at a depth within a surface of the stent. The method can additionally comprise depositing a layer of a TiN_xO_y compound on the surface of the stent where the TiN_xO_y compound is implanted.

[0008] In accordance with another aspect of the invention, a method of modifying a surface of a device, such as a stent is provided, which method comprises implanting Ti, N, or TiN into the surface of the stent and forming layer of the TiN_xO_y compound over the areas where Ti, N, or TiN has been implanted.

[0009] In accordance with yet another aspect of the invention, a method of modifying a surface of a device, such as a stent, is provided, which method comprises implanting a TiN_xC_y compound at a depth within a surface of the stent or depositing the compound on the surface of the stent.

BRIEF DESCRIPTION OF THE FIGURES

[0010] Figure 1 is a perspective view of a conventional stent having a scaffolding structure;

[0011] Figures 2A, 2B, and 2C1, 2C2, and 2C3 illustrate process steps for modifying a stent surface and modified stent surfaces in accordance with embodiments of the invention; and

[0012] Figure 3 schematically illustrates one embodiment of a reaction chamber that can be used to carry out the processes of the present invention.

DETAILED DESCRIPTION

[0013] A surface of a medical device can be modified so as to include titanium nitride oxide or a titanium nitride carbide. A medical device is broadly defined to include any implantable device such as any inter- or intraluminal device used for the release of an active agent, for upholding luminal patency, or for any other treatment purposes in a human or veterinary patient. Examples of such medical devices include self-expandable stents, balloon-expandable stents, stent-grafts, grafts (e.g., aortic grafts), artificial heart valves, cerebrospinal fluid shunts, axius coronary shunts, pacemaker electrodes, and endocardial leads (e.g., FINELINE and ENDOTAK, available from Guidant Corporation). The underlying structure of the device can be of virtually any design. The device can be made of a metallic material or an alloy. Stainless steel is one example of a commonly used material.

[0014] The present invention will be described with reference to a stainless steel stent. Figure 1 illustrates one example of a conventional stent 10, the structure of which can include struts 12 connected by elements 14. Struts 12 and elements 14 define a tubular body having an outer or tissue contacting surface 16 and an inner surface 18. Figure 2A illustrates a section of one of struts 12 as will be modified as described hereinafter. It is understood that any portion of outer surface 16, including selected areas of elements 14 can be similarly treated and that the modification is not limited to any particular region of outer surface 16 or inner surface 18 of stent 10.

[0015] Prior to surface modification of stent 10, outer surface 16 (including inner surface 18) is cleaned by argon ion bombardment. Stent 10 can be placed on a mandrel and positioned within a reaction chamber. One example of a suitable system for carrying out the process is illustrated in Figure 3, the details of which are described later in the specification. Argon gas (e.g., > 99.9% by volume) can be introduced in the reaction chamber (having a volume of, for example, 2000 cm^3) at a flow rate of about 10 to 200 sccm, for example at about 50 sccm. The pressure of the chamber can be about 50 mTorr. The RF power and frequency can be, for example, about 100 Watts and 13.56 MHz, respectively. The bias voltage applied to the stent can be from about 100 V to about 3 KV, for example about 1 KV. The cleaning process can be conducted for about 5 minutes to about 30 minutes in duration.

[0016] In one embodiment, following the act of cleaning stent 10, nitrogen ions can be implanted in surface 16 of the stent. Nitrogen can be implanted by

introduction of a nitrogen gas in the chamber followed by initiation of plasma under the parameters illustrated in Table 1:

Table 1

Process	Parameter Range	Exemplary Value
nitrogen	_	> 99.9 % by volume
gas flow rate (sccm)	10 to 200	40
volume of chamber (cm^3)	_	2000
pressure (mTorr)	0.1 to 2	0.5
RF power (watts)	10 to 1000	200
RF frequency MHz	0.2 to 2450	13.56
bias voltage stent (KV)	-20 to -60	-50
bias voltage titanium grid (KV)	-20 to -60	-45
thickness (or depth) of the implant (Å)	500 to 2000	800

[0017] Figure 2B illustrates nitrogen implanted a within surface 16, as indicated by region 20. It should be noted that the presence of a titanium grid in the reaction

chamber during the implantation procedure of nitrogen does not lead to any significant sputtering of the titanium from the grid and onto stent 10 as the nitrogen ions should be essentially incapable of sputtering the titanium off the grid.

[0018] In accordance with another embodiment, in lieu of implanting nitrogen at a selected depth within outer surface 16 of stent 10, titanium can be implanted into outer surface 16. This can be accomplished by using an argon gas (e.g., > 99.9 % by volume) instead of the nitrogen gas. The process parameters that are similar to that of Table 1 can be employed to form a titanium implant at similar depths. The purpose of nitrogen or titanium implantation is to provide a more suitable platform for modification of the surface into TiN_xO_y or TiN_xC_y.

[0019] Surface modification can be accomplished by introducing argon in the reaction chamber and initiating plasma to sputter titanium off the grid and on or into surface 16. A source gas containing oxygen and nitrogen can also be introduced into the reaction chamber for reacting with the titanium to from TiN_xO_y. By way of example, in an embodiment in which the source gas is nitrogen monoxide (NO), NO^- ions will react with titanium ions to form a titanium nitride monoxide (TiNO). Similarly, in an embodiment in which the source gas is nitrogen dioxide (NO_2), NO_2^- ions and dissociated NO^- ions will mix with titanium ions to form a mixture of titanium nitride dioxide ($TiNO_2$) and titanium nitride monoxide (TiNO). Windecker et al. has reported that coronary artery stents coated with titanium nitride dioxide or titanium nitride monoxide reduced neointimal hyperplasia in pigs by 47% and 44%, respectively.

[0020] Process parameters for modifying the surface as to include TiN_xO_y are illustrated in Table 2:

Table 2

Process	Parameter Range	Exemplary Value
gases (by volume)	argon: 20% to 80% oxygen: 10% to 40% nitrogen: 10% to 40%	argon: 20% oxygen: 40% nitrogen: 40%
gas flow rate (sccm)	10 to 200	30
volume of chamber (cm^3)	_	2000
pressure (mTorr)	0.1 to 500	50
RF power (watts)	10 to 1000	100
RF frequency MHz	0.2 to 2450	13.56
bias voltage stent (KV)	-5 to -30	-10
bias voltage grid (KV)	-5 to -30	-9
thickness of layer 22 (Å)	1000 to 50,000	5000

[0021] The negative voltage applied to stent 10 can have a frequency of up to, for example, 500 KHz and a width of 70 to about 200 microseconds. In one

embodiment, as illustrated in Figure 2C1, a TiN_xO_y layer 22 is formed on the nitrogen or titanium region 20. In accordance with another embodiment, the nitrogen gas can be introduced into the chamber prior to the introduction of the combination of the oxygen and nitrogen gases. Accordingly, region 20 may include traces of TiN or alternatively, as illustrated in Figure 2C2, a layer of TiN, as illustrated by reference number 24, may be implanted in surface 16 followed by formation of TiN_xO_y layer 22 when oxygen is introduced in the chamber. In yet an alternative embodiment, as illustrated in Figure 2C3, some of the TiN_xO_y can be implanted within surface 16, as illustrated by region 22b, in addition to having TiN_xO_y deposited on surface 16, as illustrated by region 22a. Region 22b can be from about 500 Å to about 2000 Å in depth. As is understood by one of ordinary skill in the art, a variety of modifications can be made the process parameters so as to achieve a particular cross-sectional topography.

[0022] In accordance with another embodiment in which the source gases are nitrogen and methane (CH_4), nitrogen and carbon ions will mix with titanium to form a titanium nitride carbide (TiN_xC_y) species. Titanium nitride carbides are hard materials that are corrosion-resistant and have excellent biocompatibility properties. The ratio of nitrogen to carbon, and thus the particular properties of the modified surface, can be controlled by controlling the concentrations and/or flow rates of the respective gases into the reaction chamber.

Example of the Reaction Chamber

[0023] The above-described methods can be performed by any suitable apparatus

known to one of ordinary skill in the art. On example of such plasma reaction chamber 30 is illustrated in Figure 3. Chamber 30 can be cylindrical in shape and can be fabricated from any number of suitable materials, such as, stainless steel, glass, and aluminum. By way of example, chamber 30 can be from about 4 inches (10.16 cm) to about 15 inches (38.1 cm) in diameter and from about 5 inches (12.7 cm) to about 18 inches (45.72 cm) in height.

[0024] A mandrel 32 holds a single medical device 34 (e.g., stent 10) or multiple medical devices 34 in position relative to the interior walls of chamber 30. Medical device 34 can be oriented at any position within chamber 30 as required to achieve a desired implantation or deposition. One end of mandrel 32 can be coupled to an electrode 36.

[0025] Electrode 36 can be made from of any suitable electrically conductive material including, but not limited to, steel, copper, chromium, nickel, wolfram, iron, and similar materials. A first power source 38, electrically coupled to electrode 36 via electrical feedthrough port 40, can apply negative voltage pulses to electrode 36.

[0026] In one embodiment, an insulator 42, formed of a non-electrically conductive material, including materials such as rubber, ceramic, or plastic is provided. Insulator 42 can include a connector 44, which can be either electrically coupled to first power source 38 or an independent second power source 48 for applying a voltage to a sputtering grid 50.

[0027] Sputtering grid 50 can be positioned within chamber 30 in symmetrical

conformity about medical device 34 so as to allow equal bombardment of device 24 from all directions. Sputtering grid 50 can be manufactured from titanium or, alternatively, can be made of a base material that is coated with titanium. Sputtering grid 50 can be cylindrically shaped. Sputtering grid 50 can be of solid construction or perforated. By way of example, sputtering grid 50 can be a perforated cylinder measuring approximately 0.5 inches (1.27 cm) to 3.0 inches (7.62 cm) in diameter, approximately 2 inches (5.08 cm) to 12 inches (30.48 cm) in height, and approximately 1/32 of an inch (0.08 cm) thick. The diameter of the perforations can be from about 0.125 inches (0.318 cm) to about 0.25 inches (0.635 cm). The percentage of the grid occupied by perforation, as opposed to titanium sputtering material, can be from about 40% to about 80% of the total surface area.

[0028] Gas ports 52 can be positioned on top of chamber 30, while aspiration ports 54 can positioned at or near the base of chamber 30. Gas ports 52 are used to flux a gaseous medium in liquid or vapor form into chamber 30, where it is converted into ionized plasma. Aspiration ports 54 are used after processing is complete, or when a new gas is desired, to purge chamber 30.

[0029] Additionally, an apparatus for accomplishing the method of the present invention includes a plasma-generating means. The plasma-generating means can be, for example, a radio frequency source and antenna, a microwave source, or any other suitable element known to one of ordinary skill in the art. By way of example, Figure 3 illustrates a radio frequency source 56, such as that manufactured by Dressler of Germany, and an antenna 58. In one such embodiment, antenna 58 can be a radio-frequency conducting filament that is

wrapped about chamber 30 in a helical or corkscrew-like fashion.

[0030] While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications can be made without departing from this invention in its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as fall within the true spirit and scope of this invention.